Methods

Data generated by the Environmental Protection Agency's REMAP program and the South Florida Water Management District's STA Receiving Areas Monitoring & Research and Threshold programs provided a basis for spatial coverage of the Everglades Protection Area (EPA), which encompasses Water Conservation Areas 1, 2, and 3, the Rotenberger and Holeyland Wildlife Management Areas, and Everglades National Park (Figure 1). Peat fire risk (PFR) and wading bird habitat suitability (WBHS) values were calculated from a number of variable factors that define site-specific physical and biological attributes. For each sampled location across the landscape the data for each factor were categorized, ranked on a scale of 1-5, multiplied by specific weights according to their proposed importance in the overall risk calculation, and summed to produce a single value. These values were then ranked themselves from 1-5 indicating low to high risk/suitability. All calculations were automated within a multi-worksheet Excel® file containing the raw data. For each assessment the computations were saved as a text file and imported into Arcview® 3.2 for map generation.

Figure 1. Sites in the EPA for which data was available for PFR and WBHS computations (triangles represent telemetric stage gauges).
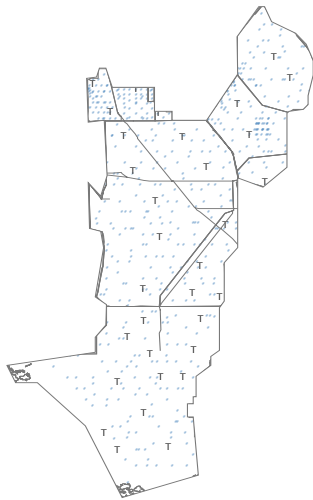
Peat fire risk assessment model

Listed below are the eight different factors included in PFR calculations and weighted according to their proposed relative contribution to peat fire.

Burn history - Incidence of fire greatly influences susceptibility to burning again for a period of time. During surface fires only the aboveground biomass of vegetation and litter layers on the ground are incinerated - the extent to which is largely dependent upon

fire temperature, water depths, and vegetation moisture levels. Rates of recovery from fire can be quite variable, since numerous variables (e.g., soil nutrients) influence regrowth. It has been reported that by approximately 2 years, the standing biomass of sawgrass can reach pre-fire loads (Gunderson and Synder, 1994 and references therein) while wet prairie vegetation may require 3 years or more for complete recovery (Herndon and Taylor, 1986). However, it may take several more years to accumulate similar amounts of above and below-ground fuel to support another fire (Gunderson and Synder, 1994).

   In contrast to surface fires, peat fires typically destroy all above-ground plant material and consume a portion of below-ground organic matter. Areas that have experienced peat fire may initially be slower to recover, since re-vegetation will occur mostly through rhizomatous growth of peripheral (unburned or surface-burned) plants or by seed germination. However, this lag phase may be offset by an increase in vegetation growth in response increased bioavailability of nutrients (Smith et al., 2001; Smith and Newman, 2001). As such, no distinction between burn types was made and the following categorization was used:

Classes	Ranking	Weight
burn >3 yrs.	5	10
burn 2.5 to 3 yrs	4	
burn 2 to 2.5 yrs.	3	
burn 1.5 to 2 yrs.	2	
burn < 1.5 yrs.	1	

Stage - Water level is, for obvious reasons, critical in determining the combustibility of marsh vegetation and especially the underlying organic soils (Wade et al., 1980). Site-specific ground elevations were determined from topographic maps also used by the South Florida Water Management Model (Fennema et al., 1994). Site-specific stage levels were determined by extrapolation from the nearest stage recorder (which assumes a flat pool over that distance) within a network of 33 gauges throughout the EPA. Water depths were then calculated as stage minus ground elevation and ranked as shown below. These ranges take into consideration that 1) capillary action from a subsurface water table will keep upper level soils moist and 2) peat soils retain moisture for considerable lengths of time following water level recession. In general, organic soils fail to ignite when moisture content is above 65 percent (Wade et al., 1980). In western WCA-2A, soil moisture levels dropped below this level only when water levels declined to < -60 cm (Smith, unpublished data).

Classes	Rating	Weight
< -2 ft.	5	7
-2 to -1.5	4	
-1.5 to –1.0	3	
-1 to -0.5	2	
-0.5 or above	1	

Duration of dry out (cumulative effects) - For each site, a value was calculated that attempts to define "cumulative" dry out - i.e., how long a site has been dry. If the water level at a site was at or above ground elevation (wet), it was assigned a value equal to the number of that particular month (e.g., March = 3, May = 5). If the water level was below ground level (dry), it was given a value of 1. To calculate a cumulative dry out value for a specific date, the maximum of all previous values (using stages for the 1st of each month) was subtracted from the number of the month for which the model was being run. Thus, sites with values of 1 (dry) throughout several preceding months ended up with high values. Conversely, sites that were wet during previous months had lower values and the more recent the site was wet, the lower the value. These risk values were then ranked 1-5 over their range and multiplied by 6 as a weighting mechanism for the overall risk calculation. Since there are so many different ways that this factor can be classified (according to temporal variability in stages), a summary table is not presented here.

Soil depth - Soil depth is an important consideration in assessing peat fire potential since the capillary action of water is lost when stages fall below the upper rock surface. When this occurs, the wicking process cannot keep upper layers of soils moist and the rate of dry out is accelerated. The following classifications for water depth in relation to soil depth were used, which take into account a certain level of microtopographic variation in the rock layer. Soil depths had to be estimated for number of sites in western WCA-1, -2A, Holeyland, and Rotenberger (STA Receiving Areas Monitoring & Research and Threshold programs) where data was not available. This was done using interpolations of REMAP data alone.

Classes	Ranking	Weight
<-0.5 ft. below rock	5	5
-0.5 to -0.25	4	
-0.25 to 0	3	
0 to 0.25	2	
> 0.25	1	

Vegetation - The combustibility of vegetation varies with tissue moisture content, structure, and chemical composition. In this regard, sawgrass is highly flammable compared to other Everglades plant species (Kushlan, 1990). Dead leaves of sawgrass remain in a standing position for long periods of time and the live material has a low water content (S. Miao, personal communication). In addition, sawgrass rhizomes are short and new ramets tend to be very densely packed (Miao and Sklar 1998). Accordingly, areas dominated by sawgrass vegetation were assigned the highest risk values. Cattail (mainly *Typha domingensis*) has a much higher water content but can accumulate large amounts of biomass, although dead leaves are less rigid and tend to fall into the water column rather than remain standing (personal observation) and there is more distance between ramets (Miao and Sklar, 1998). Wet prairie vegetation (e.g.,

Panicum hemitomon, Sagittaria lancifolia, Eleocharis spp., Rhynchospora spp.) is much shorter, thinner in stature, and tends to be comprised mainly of live tissues with little standing dead biomass. As a result, this community does not carry fire well (Gunderson and Synder, 1994) and was assigned a lower risk value. Slough communities generally exist in areas with the long hydroperiods and are dominated by water lily (<u>Nymphaea odorata</u>., <u>Nymphoides aquatica</u>) and spikerush (<u>Eleocharis</u> spp.) vegetation, both of which accumulate virtually no standing dead biomass. This habitat can be considered an extremely low risk for fire.

<u>Classes</u>	<u>Ranking</u>	<u>Weight</u>
sawgrass	5	4
sawgrass/cattail	4	
cattail/sawgrass	3	
sawgrass/wet prairie	3	
cattail	2	
cattail/wet prairie	2	
wet prairie	2	
cattail/slough	1.5	
slough	1	
shrubs/tree island	2	
slough	1	

* mixed upland vegetation in the Rotenberger Wildlife Management Area was given a rank of 5.

Soil Total Phosphorus (TP) Concentration - Phosphorus (P) is the primary limiting nutrient for Everglades vegetation and elevated levels of soil TP correspond with enhanced plant productivity and biomass (Davis, 1994; Miao and Sklar, 1998). Unimpacted regions of the Everglades typically have soil with 400 mg/kg TP or less, while moderately impacted regions show variation from 400-700 mg/kg. Concentrations of 700 mg/kg and above are usually accompanied by major changes in vegetation biomass, structure, and species composition (Craft and Richardson, 1997; **other refs**).

<u>Classes</u>	<u>Ranking</u>	<u>Weight</u>
> 700 mg/kg	5	3
600-700	4	
500-600	3	
400-500	2	
< 400	1	

Bulk density - When organic soils dry out oxidation, consolidation, and compaction occur, which results in decreased porosity and, to a certain extent, the irreversible loss of water-holding capacity (Myers and Ewel, 1990 and references therein; Rogers and Sothers, 1996). The bulk densities of soils from regions that experience severe dry out are typically much higher than those from longer hydroperiod marshes (Newman et al.,

1998; Reddy et al., 1999?). Bulk density values were therefore ranked over their range and weighted by 2 in the final risk calculation.

Classes	Ranking	Weight
>0.4	5	2
0.3 to 0.4	4	
0.2 to 0.3	3	
0.1 to 0.2	2	
<0.1	1	

Soil type - Peat soils contain a higher percentage of undecomposed organic matter than marl (also known as calcitic mud), which is comprised of hardened layers of periphyton-derived calcium carbonate (Gleason and Stone, 1994). Dried peat soils are much more loosely packed (leaving more airspace) and presumably more flammable than marl. Sandy soils tend to have the lowest organic matter content and are therefore much less combustable. Peat, marl, and sand soils were ranked 5,3, and 1, respectively. Combinations of these soil types were given intermediate ranks. This factor was included as an unweighted component of the overall risk calculation.

Classes	Ranking	Weight
Peat	5	1
Peat/Marl	4	
Marl	3	
Marl/Sand	2	
Sand	1	

Overall PFR calculation -

PFR = (burn-history rank$*$10) + (water depth rank$*$7) + (duration of dry out rank$*$6) + (soil depth rank$*$5) + (vegetation type rank$*$4) + (soil TP rank$*$3) + (bulk density rank$*$2) + (soil type rank)

The PFR values calculated from the equation above were themselves ranked 1 to 5 corresponding to an entire range of possibilities (i.e., highest and lowest possible risk values dictated by the equation) so that temporal changes could be detected. The final index values were interpolated and mapped using Arcview ver. 3.2. Sites were color coded according to index value.

Wading Bird Habitat Value Assessment Model

Droughts can impact wading birds by reducing the suitability of foraging sites. The use of foraging sites by wading birds decreases rapidly after the surface water disappears (Bancroft et al. 1994) and birds are forced to fly increasing distances from the colony to

find suitable foraging habitat (i.e., presence of surface water). At some distance from the nest, however, it becomes energetically unprofitable, or birds are limited by the time takes, to transport food to the young. Thus one measure of suitability of a foraging site is distance from a colony, with closer sites having a higher suitability. Distance thresholds that cause abandonment vary among species, stage of the nesting cycle, and prey availability at foraging sites. Droughts can also affect the suitability of wading bird nesting. Nesting sites are adversely impacted when the surface water directly under the colony disappears, thus providing access to mammalian predators (Rodgers 1987, Frederick and Collopy 1989). When sites go dry the adults may abandon the colony (Bancroft et al. 1994).

Wading bird habitat values were developed using Wood Stork (*Mycteria americana*) and White Ibis (*Eudocimus albus*) colony locations, colony nest numbers, and species-specific foraging distances. Wood Stork and White Ibis were given priority over other wading bird species since the Wood Stork is a federally Endangered Species and the White Ibis is a Florida Species of Special Concern. Also, these two species have shown dramatic population declines over the past 70 years (Ogden 1994, Crozier et al. 2000). Finally, historic nesting data have shown that during drought years, few herons and egrets attempt to nest whereas large numbers of Wood Storks and White Ibis may (Crozier et al. 2000). Thus, focusing attention on the species that have the best chance of nesting success during drought years appears the most prudent management strategy.

Water depth suitability for foraging - A range of 0-0.5 ft. has been postulated as an optimal water depth range for wading bird foraging in general (**Gawlik, in press**). In this model, however, water depths between -0.3 ft. (-10 cm) and 1 ft were included in the highest suitability category and assigned a value of 1. Although negative values intuitively suggest unsuitable habitat, this range presumes a certain amount of micro-topographic variation in the immediate surrounding area that would allow surface water to occur in depressions. Similarly, a 1-ft. depth would in reality translate to shallower depths over higher landscape features such as sawgrass ridges. Water depths that were higher or lower than these end points received successively lower suitability values as indicated below. These categorizations essentially follow a modified bell curve, whereby foraging suitability is constant over an "optimal" range of water depths but declines rapidly in linear fashion beyond minimum and maximum thresholds. The final values were then ranked on a 1-5 scale over their range in order ensure that water depth carried equal weight when combined with other components of the assessment.

Classes	Transformed values	Rank	Weight
< -0.3 ft.	-0.3/Water depth	1-4 according to magnitude	1
-0.3 to 1	1	5	
> 1	1/Water depth	1-4 according to magnitude	

Rate of recession – Receding water decreases the amount of available living space for aquatic macrofauna and effectively concentrates prey items in shallow water for wading birds. In general, a rapid rate of recession seems to produce good nesting effort (Kahl 1964, Frederick and Spalding 1994). When recession rate drops below 0.5 cm per day (0.1 ft./week) or when it reverses, nest abandonment can occur (Kushlan 1976b, Frederick and Collopy 1989a, Frederick and Collopy 1989b). Recession rates of the month previous to the specific date of assessment were calculated from stages and scaled according to the following criteria.

Classes	Rank	Weight
0.1 ft/wk or above	5	0.5
0.08 to 0.1	4	
0.06 to 0.08	3	
0.04 to 0.06	2	
< 0.04	1	

A water depth adjustment was incorporated into this component based on the presumption that recession rate is considerably less important when water depths are sub-optimal (e.g., recession rate is irrelevant when sites are dry).

Water Depth Rank (WDR)	adjusted by recession rate (RR)
1	WDR*5 + RR
2	WDR*5 + RR*2
3	WDR*5 + RR*3
4	WDR*5 + RR*4
5	WDR*5 + RR*5

Colony locations and relative colony sizes - Distances from each Wood Stork colony were calculated so that for each site there were x number of distances from x number of colonies. Each of these distances was then scaled based on a foraging range of 0-34 km (Kahl, 1964; Bryan and Coulter 1987, Bryan et al. 1995). Values exceeding this threshold received a value of 0, whereas values within this range were transformed by the linear function y = 1-(distance from colony in km/34km). In this way, closer sites received higher values. Each distance-related rank value for a particular site was then multiplied by the number of estimated nests in the colony from which the distance was calculated. Nest numbers were updated on a monthly basis by helicopter survey. Finally, these nest-weighted values were summed to obtain a number that identified a site's value as wading bird habitat based on 1) proximity to multiple colonies and 2) the relative importance (size) of the colonies.

The same procedure was repeated with White Ibis colony data using a foraging range of 0-18 km (Bancroft et al., 1990) so that two separate species values were generated for every map site. Because Wood Storks are listed as a federally endangered species, however, they are considered a higher priority from the standpoint of environmental

management. Accordingly, habitat values were weighted 1.5:1 in favor of Wood Storks. These two values for each site were then summed to obtain final numbers reflecting a combined species habitat value, which themselves were ranked 1-5 over their entire range.

A simple time switch was incorporated in the model that turns the nesting component "on" during the breeding season and "off" during the rest of the year. During the off-season, the term for site proximity to colonies and their nest numbers is excluded from the risk equation. During the breeding season, all distance-related ranks of 5 (i.e., closest sites to nests) were substituted with water depth ranks to account for the potential for predatory access to nests.   This assures that dry sites in close proximity to large colonies have a low habitat suitability rank. The following water depth classifications were used for this component:

Water depth (ft.)	Rank (as related to nest accessibility)
<-0.3 ft	1
-0.3 to -0.2	2
-0.2 to -0.1	3
-0.1 to -0.1	4
0 or above	5

Integration of all factors - Water depth, recession, and distance (weighted by nest numbers and species)-related ranks for each map site were weighted and summed to produce the final WBHS values, which were themselves ranked 1-5 for mapping.

WBHS calculation:

Habitat suitability = (water depth-related rank*2) + (recession-related rank) + (distance adjusted by colony size-related rank*2)

Example output - peat fire risk May 2001